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ABSTRACT

Concentrations of vitellogenin, 17-betaestradiol (β), 11-ketotestosterone (K), and polychlorinated biphenyls (PCBs) were measured in 461 common carp (*Cyprinus carpio*), largemouth bass (*Micropterus salmoides*), and brown bullhead (*Ameiurus nebulosus*) from eight sites in a 230-km reach of the Hudson River during May 18-June 26, 1998. Endocrine biomarkers in fish plasma were compared to PCB concentrations in fish tissues and bed sediment. Elevated concentrations of PCBs in sediment (730 to 2500 $\mu\text{g/kg}$) and fish (200 to 1250 $\mu\text{g/g}$) were measured near a major PCB source and from the next two sites downstream; concentrations tended to decrease with distance downstream. Vitellogenin was detected in plasma of 8 to 20% of mature male carp and bass near the PCB source. The β/K ratio, usually less than 1 in males and greater than 1 in females, exceeded 1.4 in all male bass and about 35% of male carp and bullhead ≥ 1 km downstream. The ratio was less than 1 in 20 to 92% of females for all three fish species near the PCB source and 55 km downstream. PCB concentrations in sediment were significantly correlated with PCB concentrations in tissue of male and female carp, bass, and bullhead ($r=0.81$ to 0.92) and to vitellogenin concentrations in male carp and bullhead ($r=0.68$ to 0.83). PCB concentrations in fish tissue were correlated with vitellogenin concentrations in male carp ($r=0.90$) and with β/K ratios in male carp ($r=0.96$). Evidence of endocrine modulation in plasma of male and female fish at sites with high PCB concentrations in bed sediment and in fish tissues indicate that PCBs and (or) other endocrine disruptors may adversely affect gametogenesis and health of resident fish populations.

INTRODUCTION

- Changes in endocrine biomarkers, and potential disruption, has been identified in fish from across the U.S. (Goodbred et al. 1996).
- The endocrine system produces hormones that maintain homeostasis, reproduction, development, and/or behavior.
- Vitellogenin is an egg-yolk precursor protein, produced by the liver of female fish in response to increased estrogen levels.
- 17-betaestradiol is a sex hormone of females.
- 11-ketotestosterone is a sex hormone of males.
- Exogenous contaminants can mimic hormones or mitigate their effects, alter biomarker levels, and disrupt the endocrine system.
- Endocrine disruption can lead to demasculinization or feminization of males or defeminization or masculinization of females (USEPA 1997a).
- PCBs and other contaminants can mimic estrogen and may disrupt the endocrine system of aquatic organisms (Goodbred et al. 1996).
- Elevated PCB concentrations in fish, sediment, and water of the Hudson River (fig. 1) are well documented (USEPA 1997b).
- PCBs in Hudson River fish have resulted in no-consumption advisories and declaration of 197 river miles as a superfund site (USEPA 1997b).
- The effects of PCBs on the endocrine system of Hudson River fish are generally unknown.
- The effects of PCBs and potential endocrine disruption on the fish fertility and resident Hudson River populations have not been documented.
- Proposed dredging of bottom sediments to remove PCBs from the Hudson River is controversial.
- Preliminary data from mature-stage fish are analyzed and summarized herein to test two hypotheses (see below).

Hudson River Basin

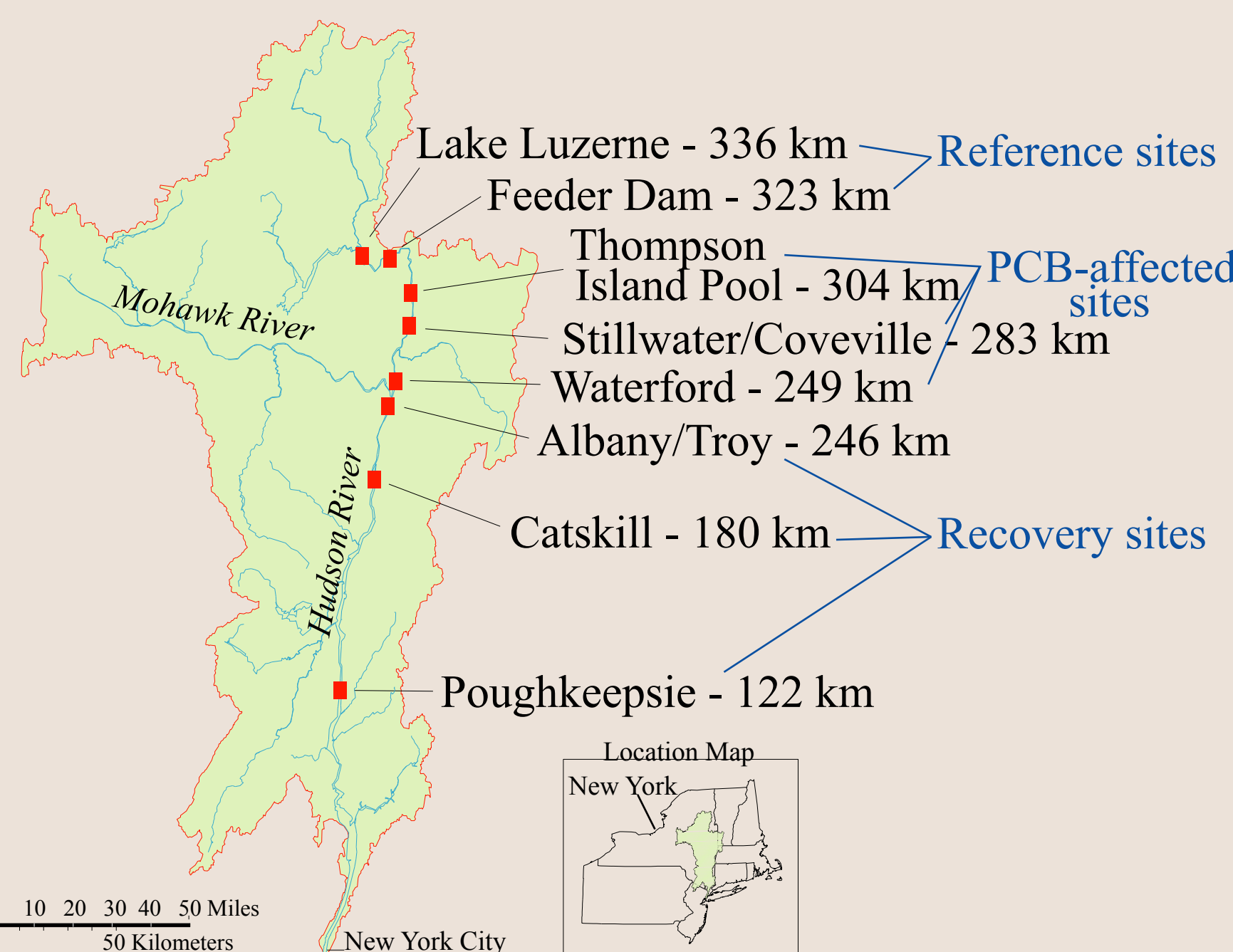


Figure 1. Study sites in the Hudson River Basin, and distance from mouth (in kilometers) at Battery Park, New York City.

HYPOTHESES

- Normal levels of biomarkers - vitellogenin, 17-betaestradiol, and 11-ketotestosterone are altered in fish from sites with high PCB concentrations in bed sediment and fish tissues.
- If endocrine biomarkers are affected, adverse effects on the reproductive system of male or female fish should be indicated by changes in gonad histopathology of male and female fish.

MATERIALS & METHODS

- The U.S. Geological Survey and New York State Dept. of Environmental Conservation collected 461 carp, bass, and bullhead (and closely related congeners) from 8 sites (fig. 1) in the Hudson during May and June, 1998.
- Fish lengths and weights were recorded, external and internal anomalies noted, scales/spines collected, blood drawn, and liver and gonads removed.
- Fish were frozen, transferred to a processing lab, filet (edible portion) homogenized, and PCB residues measured by gas chromatography.
- Plasma samples were frozen, shipped to a lab at the University of Florida, Gainesville, and vitellogenin, 17-betaestradiol, and 11-ketotestosterone were analyzed by methods described in Schmitt and Dethloff (2000).
- Sediment PCB residues were measured from samples collected in 1998 at 5 sites, (Waterford, Poughkeepsie, and Feeder Dam data were from 1993-97).

RESULTS & DISCUSSIONS

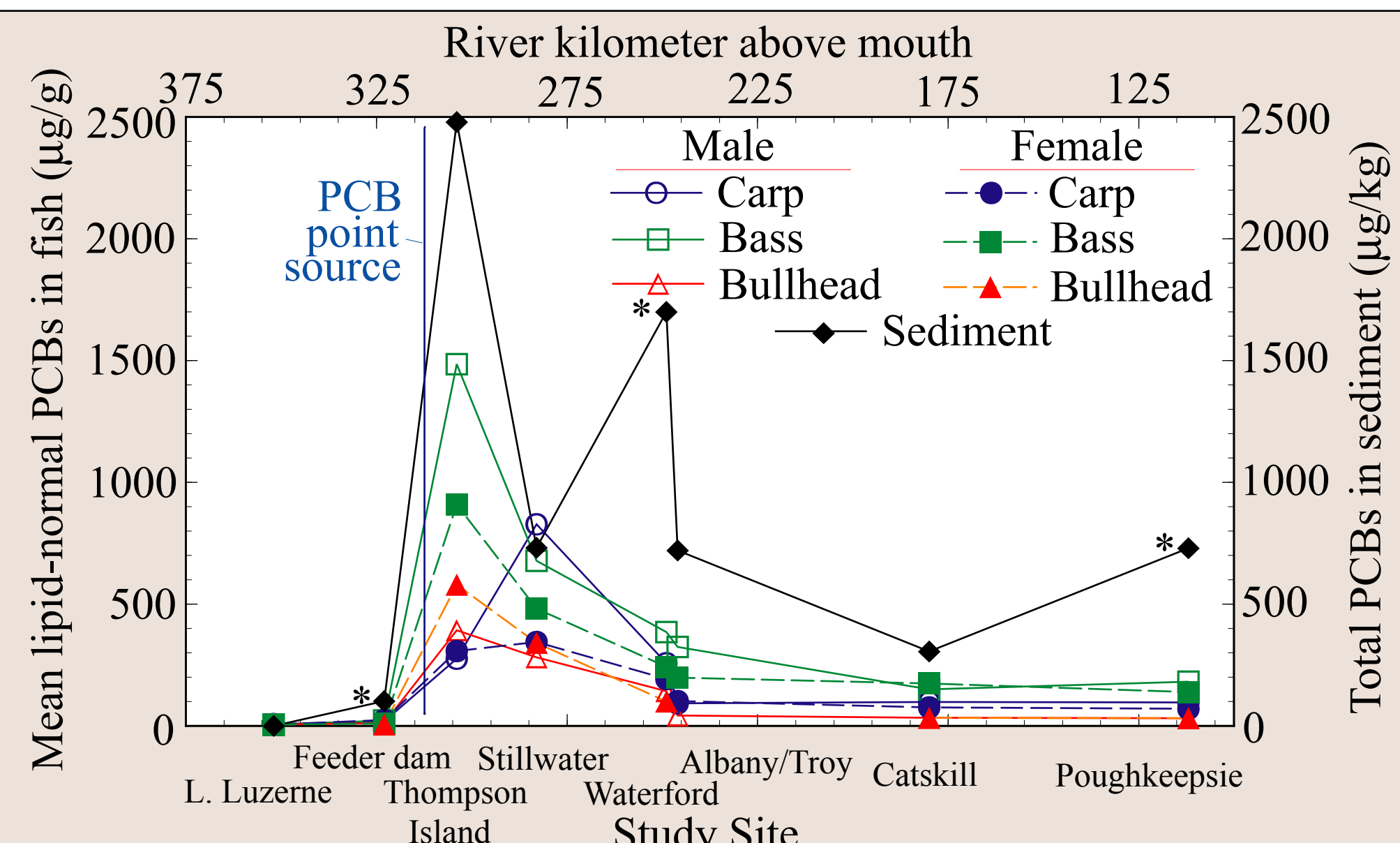


Figure 2. Mean lipid-normalized PCBs in fish tissue and total PCB concentrations in bed sediment [* denotes sediment data from 1993 and 1997]. Data from about 10 males and 10 females were analyzed for each species. Lipid-normalized total PCBs in fish tissues, and total PCB concentrations in sediment were highest at Thompson Island Pool, Stillwater/Coveville, and Waterford, all downstream from a major PCB point source. PCB concentrations decreased at Albany/Troy, Catskill, and Poughkeepsie and were low at the reference sites, (Lake Luzerne and Feeder Dam).

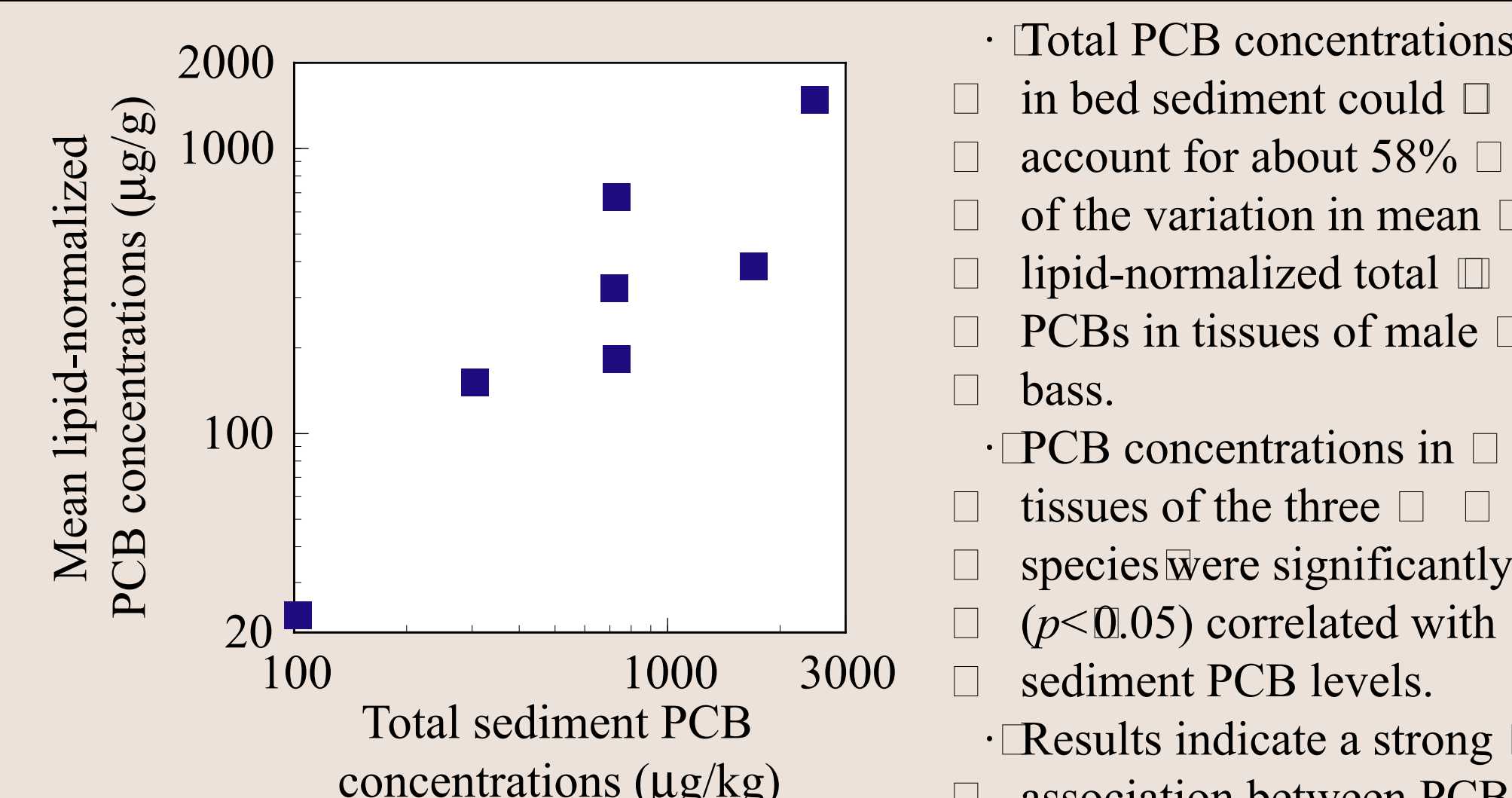


Figure 3. Relation of mean lipid-normalized total PCBs in male bass to total PCB concentrations in bed sediment at Hudson River sites.

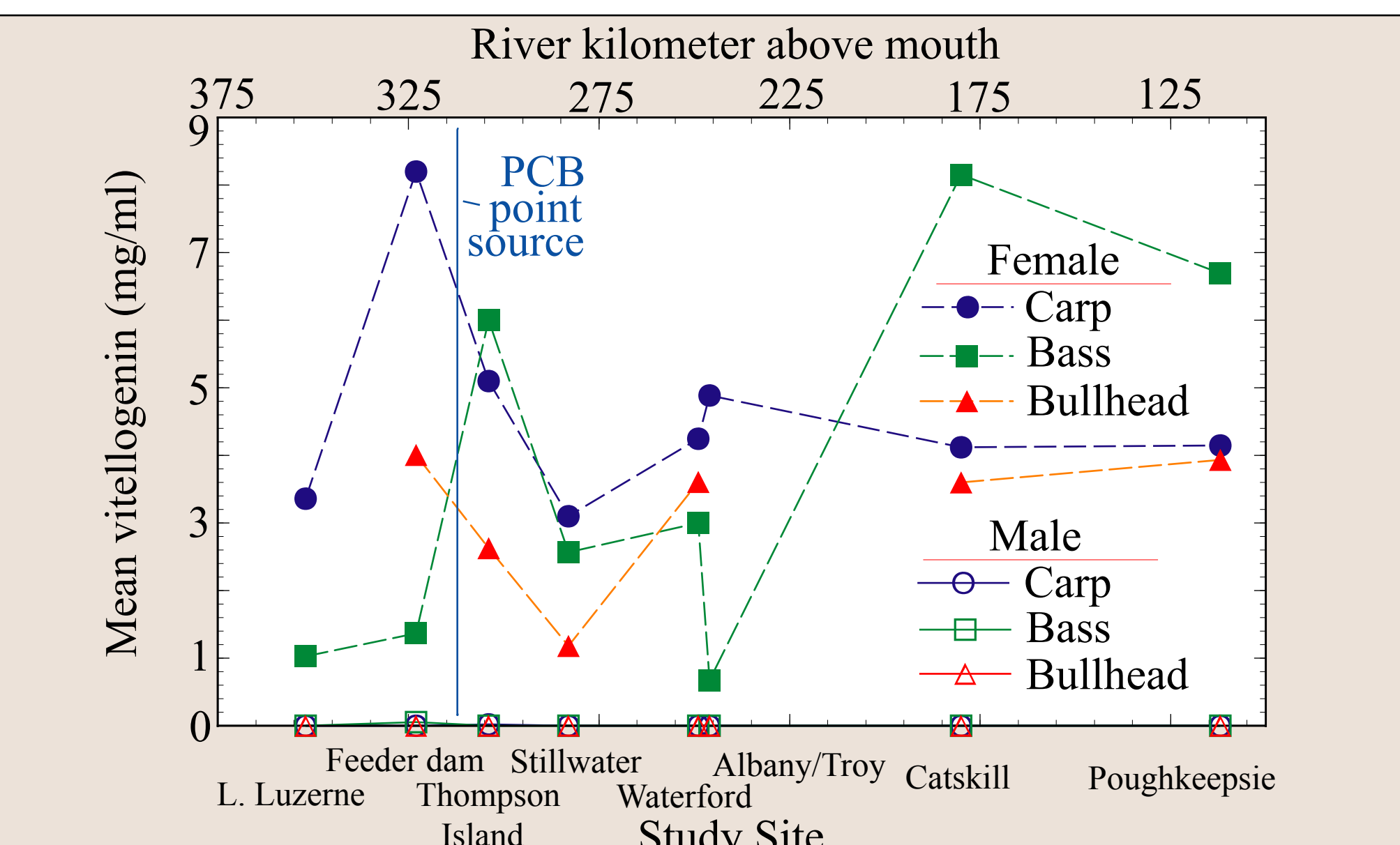


Figure 4. Mean vitellogenin concentration in plasma of male and female fish, [vitellogenin levels of males averaged near zero and are on the x-axis]. Vitellogenin concentrations in female carp and bullhead were generally lower at PCB-contaminated sites than at reference and recovery sites. Vitellogenin concentrations in female bass were low at 1 reference and 2 PCB-contaminated sites and high at 1 reference and 2 recovery sites. Altered vitellogenin levels in female fish at several sites may be related to high PCB concentrations, but analogous effects in bass at uncontaminated sites indicate other contaminants may also affect their endocrine systems.

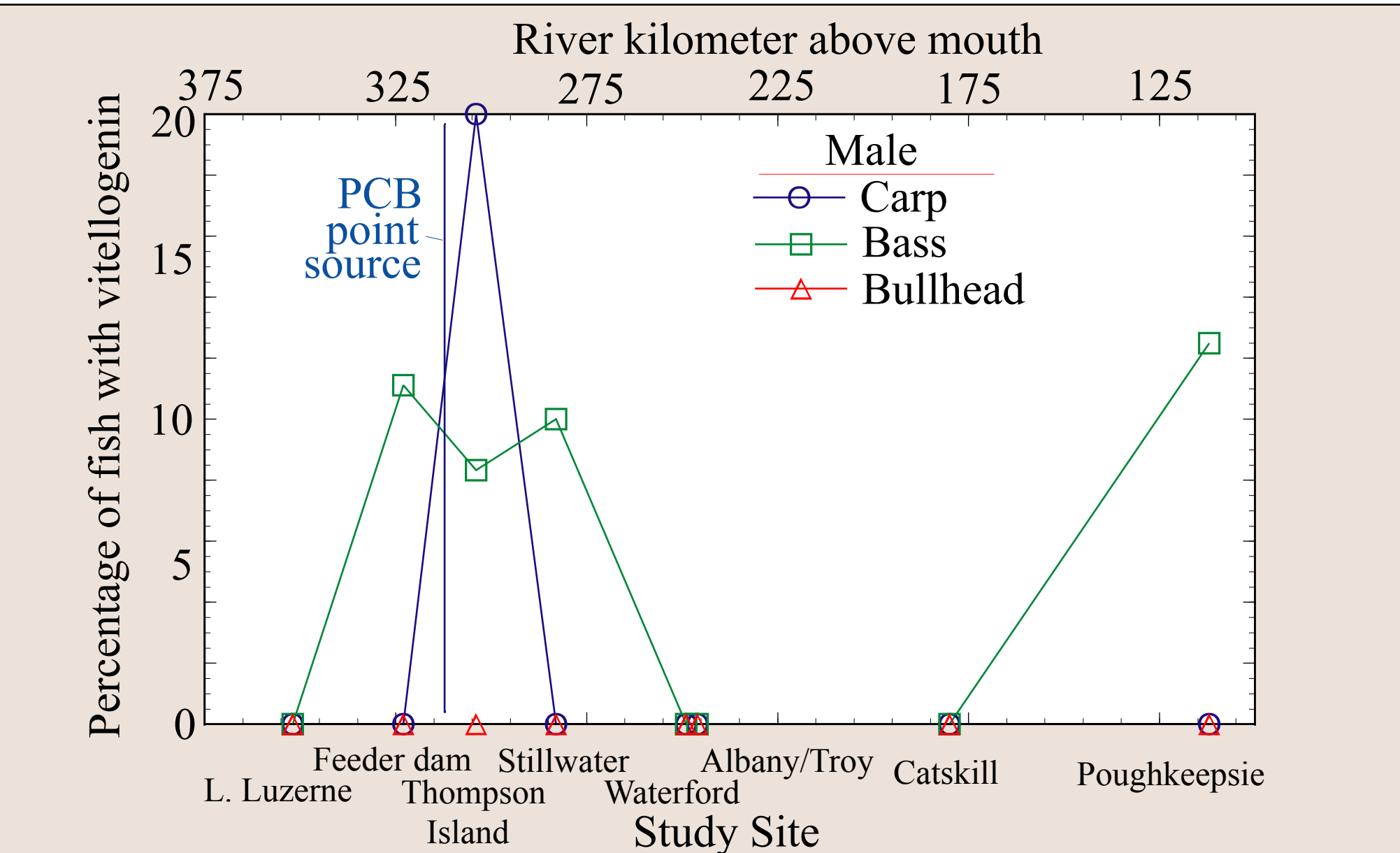


Figure 5. Percentage of male fish with more than 0.1 mg/ml (bullhead) or 0.01 mg/ml (bass and carp) of vitellogenin in their blood plasma. Vitellogenin does not normally occur in plasma of male fish, but 20% of male carp near the source, and 8 to 10% of male bass at the two most PCB-contaminated sites, had concentrations above background levels. Vitellogenin was also evident in 11 to 12% of male bass at Poughkeepsie and Feeder Dam. The vitellogenin in male bass at Poughkeepsie may be related to dioxin contamination because it is an endocrine mimic and unpublished data indicate that dioxin levels in fish tissues peak at Poughkeepsie. These data suggest PCBs and other estrogen mimics may have minimally affected the endocrine system of male carp and bass at the two PCB contaminated sites and at two others not highly contaminated by PCBs.

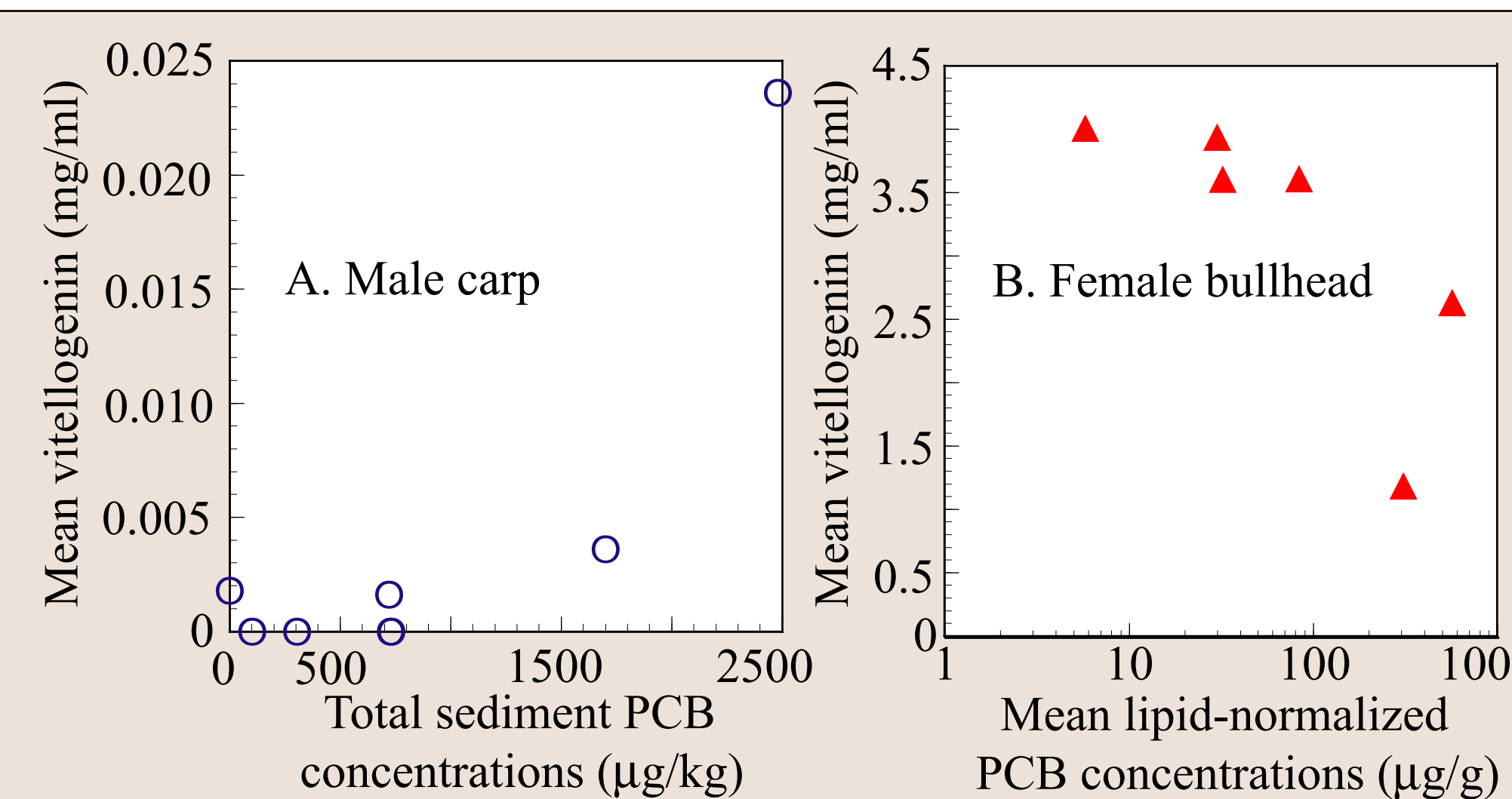


Figure 6. Relation of (A) vitellogenin concentration in male carp to total PCB concentrations in bed sediment, and (B) vitellogenin levels in female bullhead to mean lipid-normalized PCBs in tissues at 8 Hudson River sites. Mean vitellogenin concentrations in male carp ($r=0.83$, fig. 6A) and male bullhead ($r=0.68$) were correlated with total PCB levels in bed sediment. Vitellogenin concentrations in male bass were negatively correlated ($r=-0.76$) to total PCB concentrations in bed sediment. Vitellogenin levels in male carp were correlated with total and lipid normalized PCBs in tissues ($r=0.90$), but not in male bass or bullhead. Vitellogenin levels in female fish were not correlated with total PCB concentrations in bed sediment but were negatively related to lipid-normalized PCB levels in tissues of female bullhead ($r=-0.78$, fig. 6B). Non-PCB contaminants may affect vitellogenin concentrations in male and female bass and female bullhead and produce the observed relations.

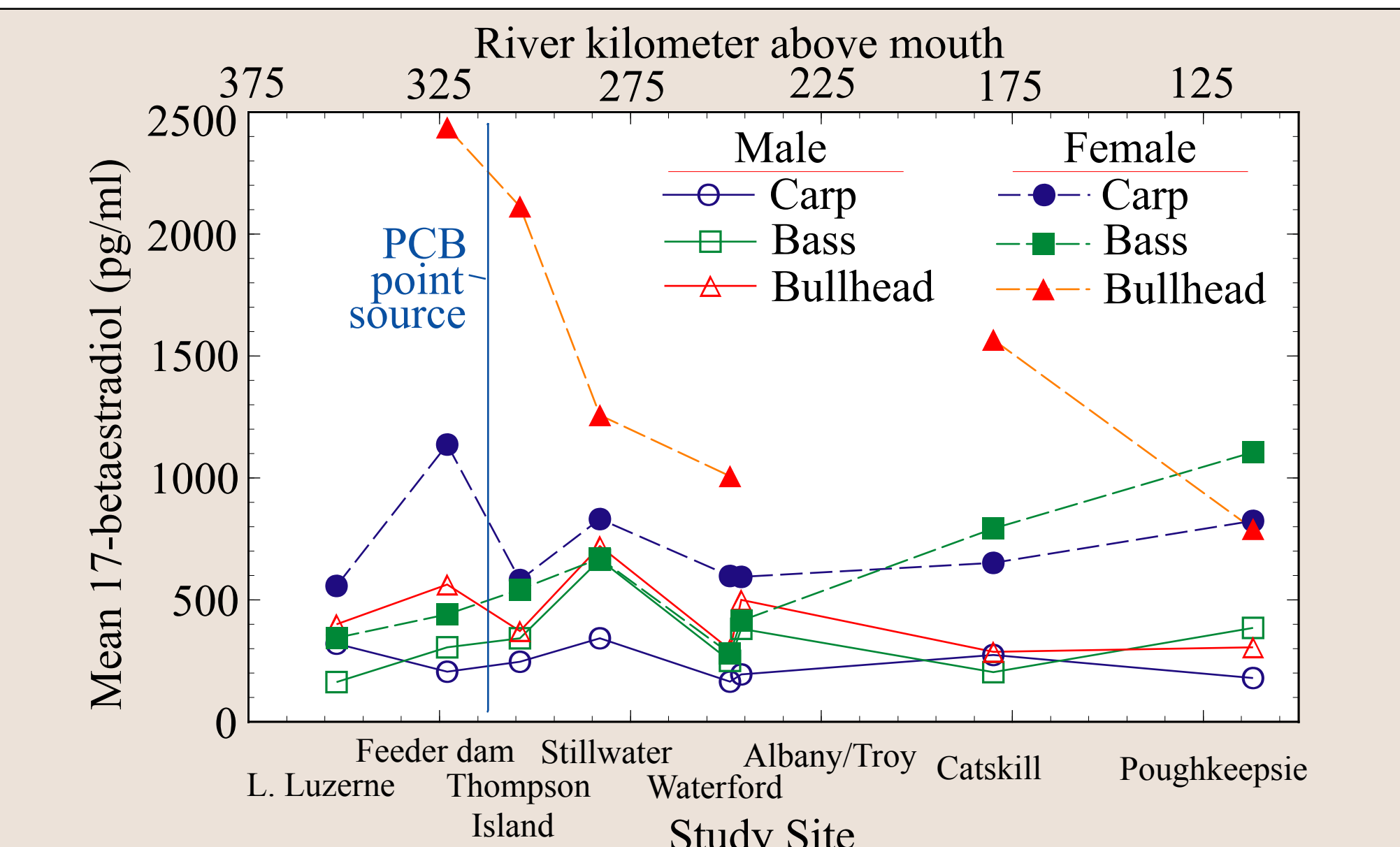


Figure 7. Mean 17-betaestradiol level in plasma of male and female fish. Mean 17-betaestradiol levels in male fish were typically lower than, and parallel concentrations in female fish. Mean 17-betaestradiol concentrations in all fish were not correlated with total sediment PCBs, but levels from female carp were significantly correlated ($r=0.78$) with lipid-normalized total PCB concentrations in carp. Mean 17-betaestradiol concentrations in male bass were similar to those in female bass at the Stillwater, Waterford, and Albany/Troy sites.

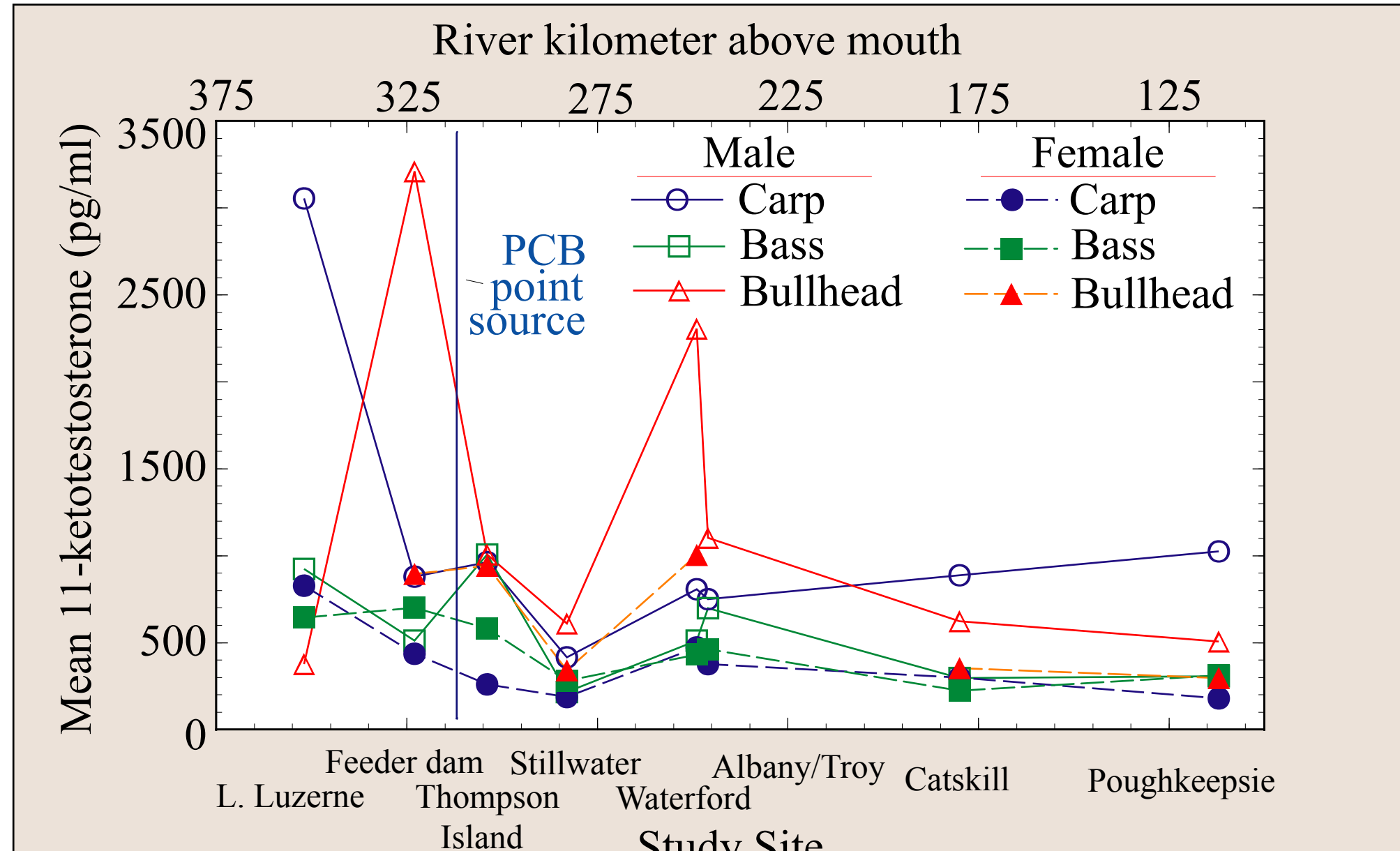


Figure 8. Mean 11-ketotestosterone concentration in male and female fish. Mean 11-ketotestosterone concentrations were generally lowest in male and female fish at Stillwater. 11-ketotestosterone levels in male carp were highest at Lake Luzerne; those in male bass are relatively low throughout the basin. Levels in male bass were lower than in females at Feeder Dam and Stillwater and equal to those in females at Thompson Island and Poughkeepsie. 11-ketotestosterone levels in male bullhead were high at one reference site and Waterford and low at sites downstream and at another reference site.

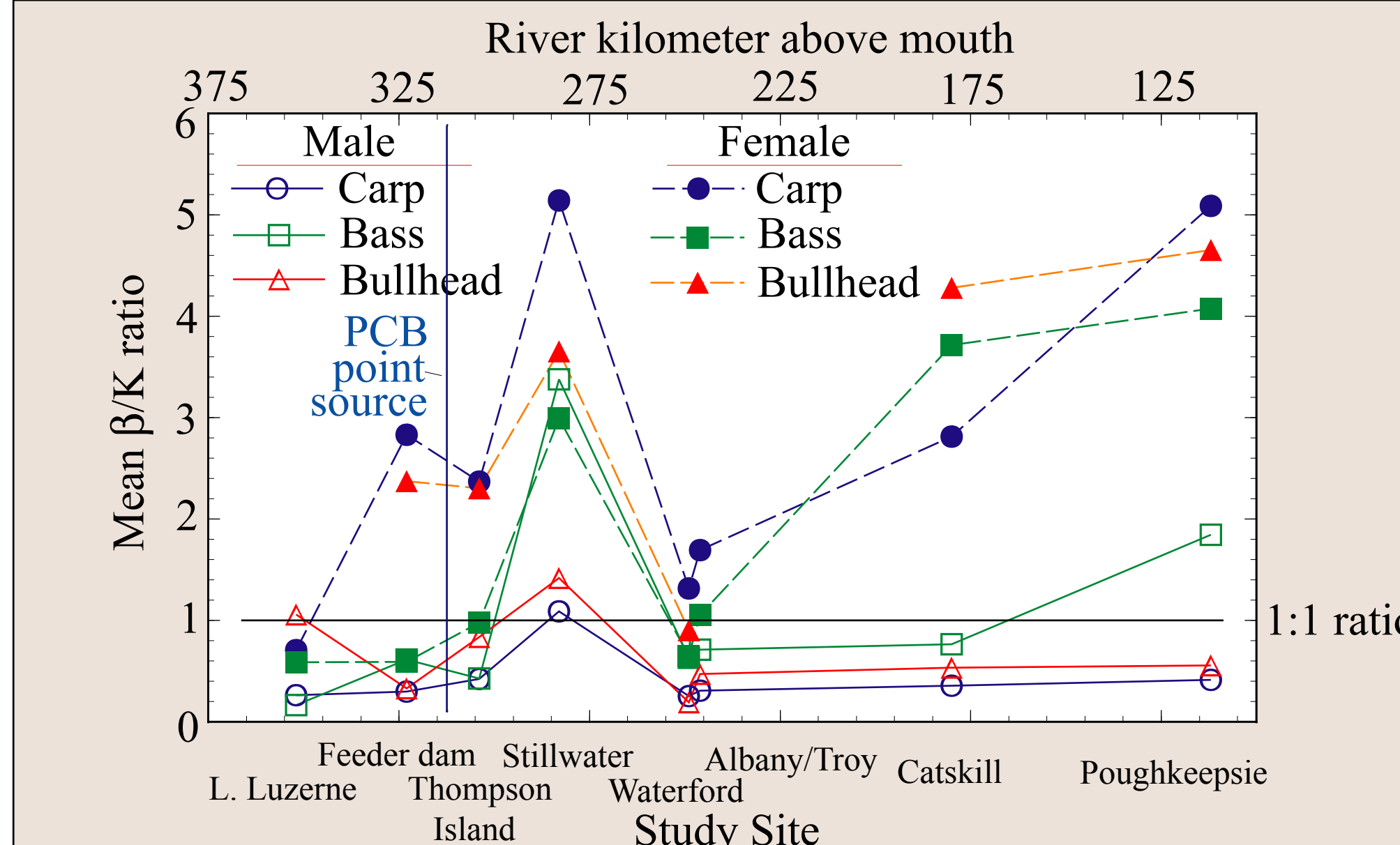


Figure 9. Mean ratio of 17-betaestradiol to 11-ketotestosterone (β/K ratio) for male and female fish. The mean ratio of 17-betaestradiol to 11-ketotestosterone (β/K ratio) was usually greater than 1 for mature female fish and less than 1 for male fish. The average ratio was greater than 1 for males of all fish species at Stillwater/Coveville. The average ratio was less than 1 for female carp at Lake Luzerne, for female bullhead at Waterford, and for female bass at Lake Luzerne, Feeder Dam, Thompson Island Pool, and Waterford.

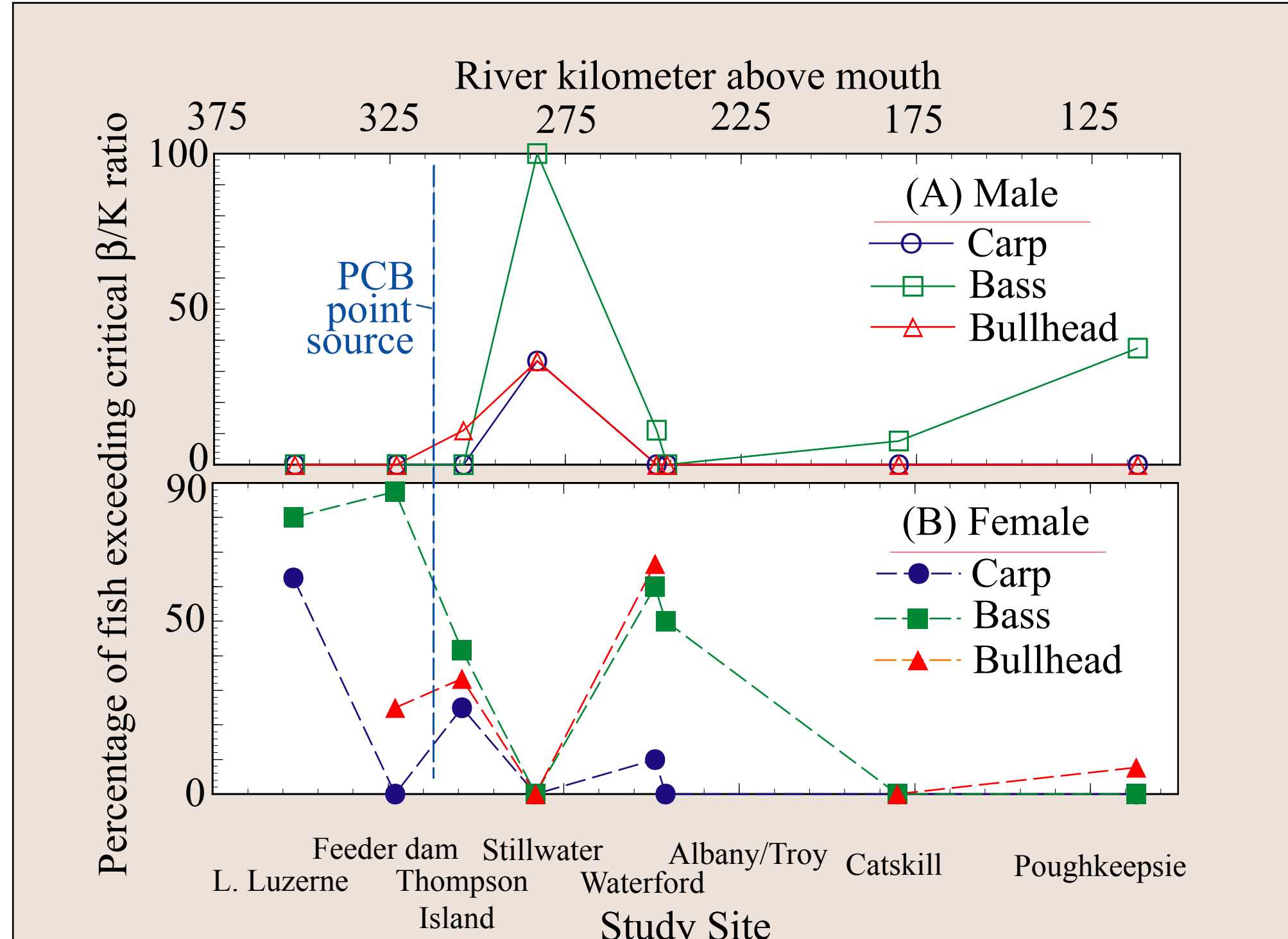


Figure 10. Percentage of (A) male fish with a β/K ratio greater than 1.4 and (B) female fish with a β/K ratio less than 0.8. All male bass and 34% of male carp and bullhead at Stillwater, and 38% of male bass at Poughkeepsie, had a β/K ratio greater than 1.4 (fig. 10A). High ratios correspond to decreased 11-ketotestosterone and increased 17-betaestradiol levels in male fish at Stillwater and Poughkeepsie. Altered β/K ratios in male fish at Stillwater and only moderate β/K concentrations in sediments indicate that contaminants, other than PCBs may be responsible for the variations observed in the β/K ratio and in other biomarkers. About 64% of female carp at Lake Luzerne, and 80 to 88% of female bass of Lake Luzerne and Feeder Dam, had β/K ratios less than 0.8 (fig. 10B).

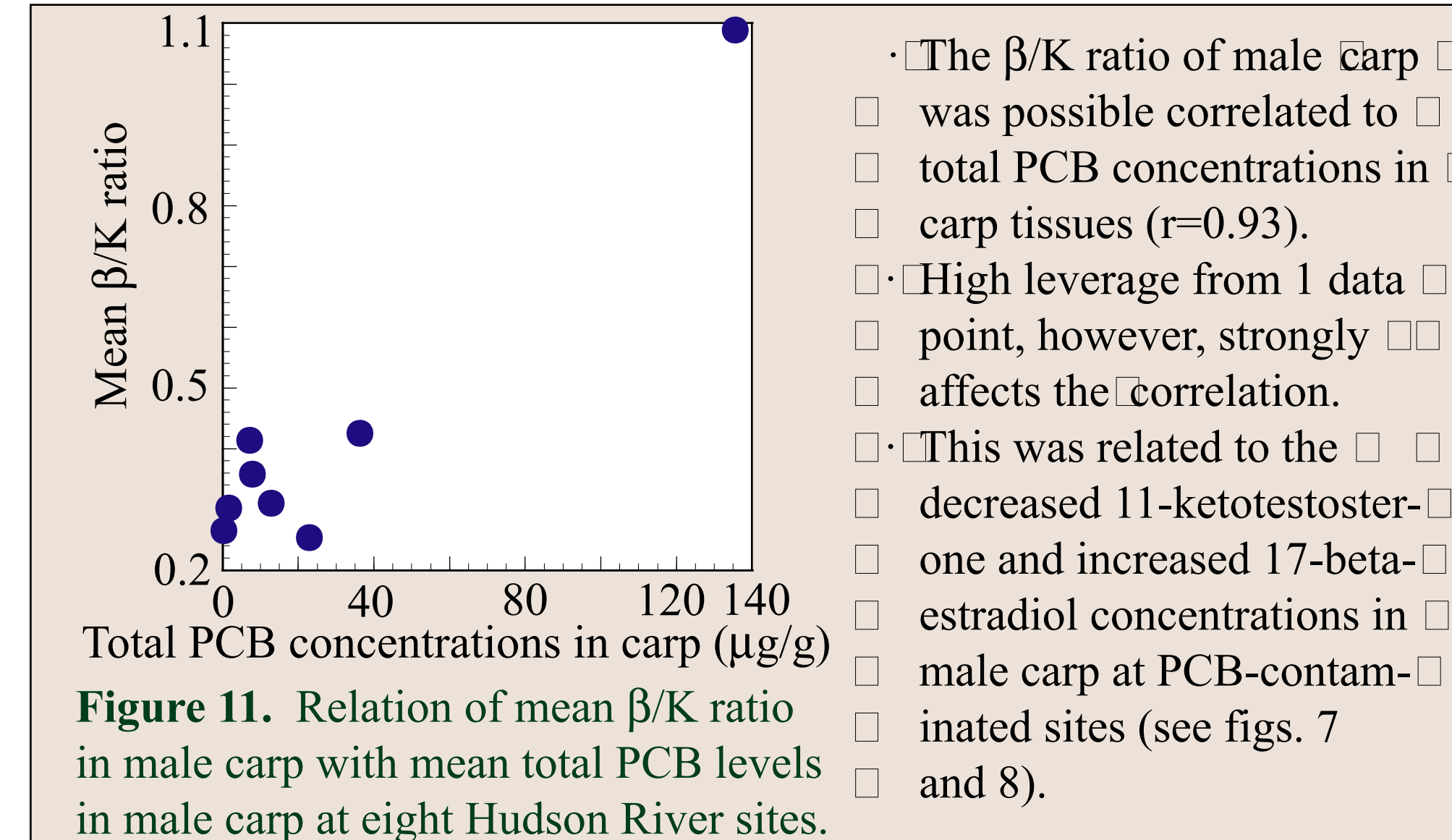


Figure 11. Relation of mean β/K ratio in male carp with mean total PCB levels in male carp at eight Hudson River sites.

Table 1. Significant ($p < 0.05$) + and - correlations of sediment PCBs and total or lipid-normalized tissue PCB concentrations with biomarkers in male and female fish from eight sites on the Hudson River.

Independent Variables	Significant correlations			
	Dependent	Carp	Bass	Bullhead
Sediment PCBs	Vitellogenin	+	-	+
	17-betaestradiol	+	-	+
	11-ketotestosterone	+	-	+
	β/K ratio	+	-	+
Tissue PCBs	Vitellogenin	+	+	+
	17-betaestradiol	+	+	+
	11-ketotestosterone	+	+	+
	β/K ratio	+	+	+

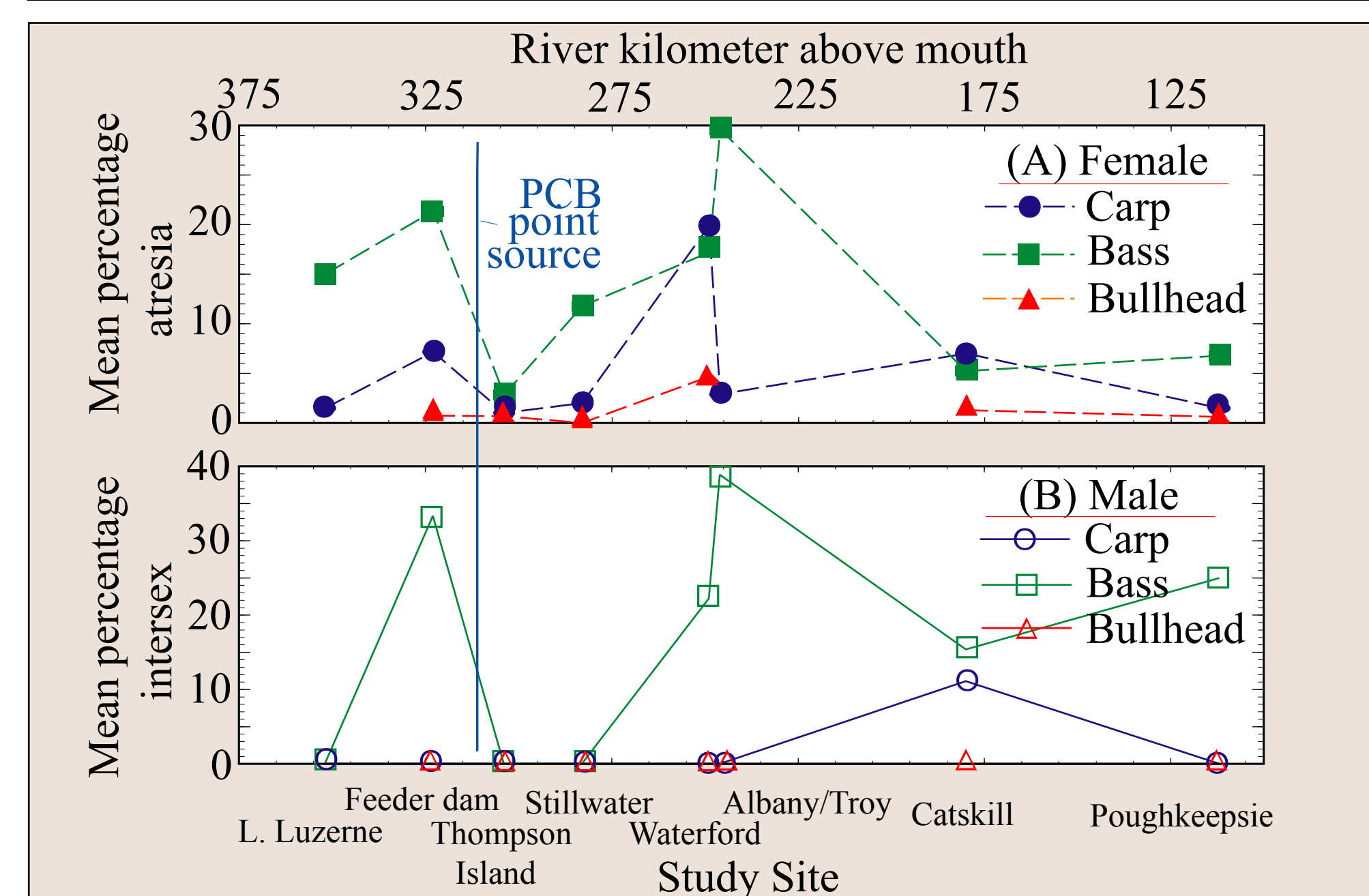


Figure 12. Percentage (A) female fish with atresia (reabsorbing oocytes), and (B) male fish with intersex (developing oocytes), in their gonads. The mean percentage of atresia female fish gonads (fig. 12A) indicate that egg reabsorption was generally lowest in female carp, bass, and bullhead from the most highly PCB-contaminated sites and that it was highest at less contaminated sites, (Albany/Troy and Feeder Dam). Similar trends were evident for the proportion of male fish that exhibited developing oocytes (intersex) in their gonads (fig. 12B). The percentage of male bass exhibiting intersex were lowest at the most highly PCB-contaminated sites (Thompson Island Pool and Stillwater) and percentages increased at sites upstream and downstream (fig. 12B).

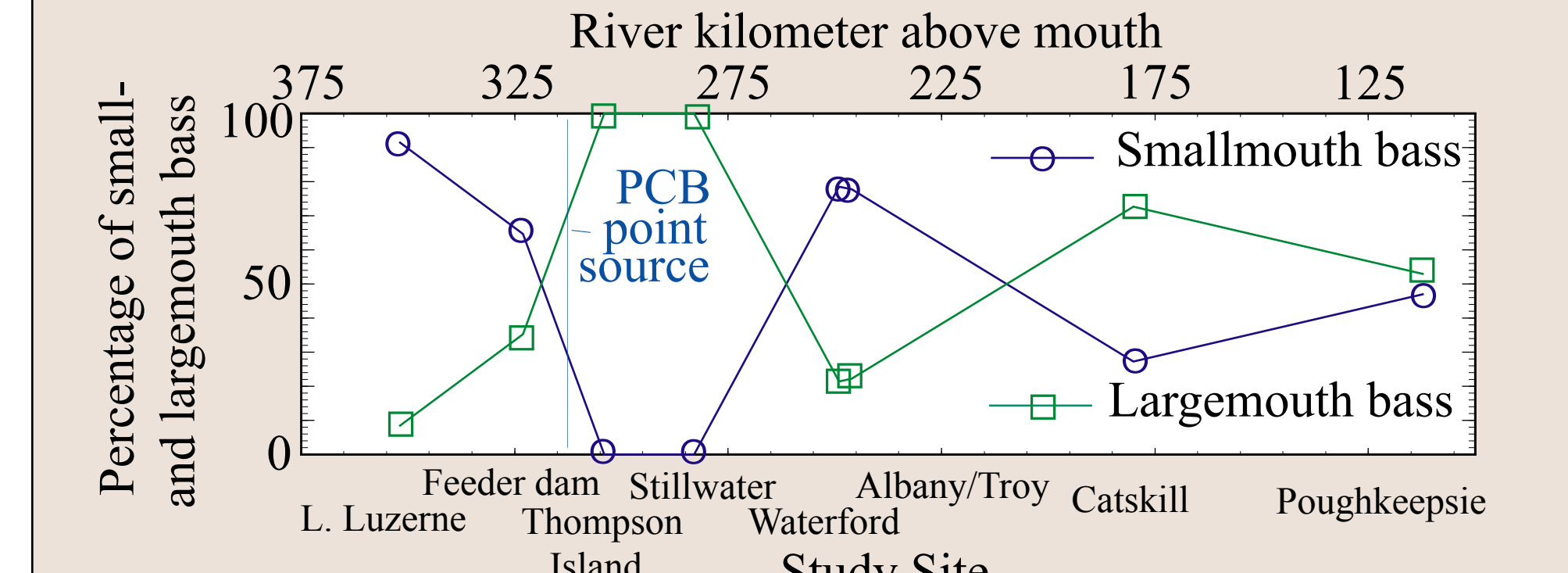


Figure 13. Percentage of smallmouth and largemouth bass sampled at sites. Intersex and atresia levels at the most highly PCB-contaminated sites (fig. 12) were unexpected if PCBs adversely affected fish endocrine systems. The response of bass may (within limits of our sample) be related to the proportion of smallmouth bass (*Micropterus dolomieu*) at each site; (a) Largemouth predominate at sites in the lower basin, and smallmouth predominant at Albany/Troy and at sites above Thompson Pool (fig. 13). (b) Largemouth were the only black bass species collected at the most PCB-contaminated sites in the upper basin. (c) The normal proportion of intersex male and atresia in smallmouth bass was typically higher (30 to 50%) than in largemouth bass (10 to 15%). Elevated levels of atresia and intersex in smallmouth bass over extended periods at Thompson Island Pool and Stillwater, could hypothetically have inhibited their reproductive systems and affected local populations.

CONCLUSIONS

- PCB concentrations in the environment directly affect PCB residues in fish.
- Endocrine biomarkers are altered to different degrees in largemouth bass, common carp, and brown bullhead.
- PCBs in the Hudson River may be partly responsible for observed variations in endocrine biomarkers of target fish species.
- Altered biomarker levels at sites with low PCB concentrations suggest that other contaminants can also affect the endocrine system of target species in parts of the basin.
- Site-to-site differences in endocrine biomarkers were most evident in carp and, to a lesser extent, in bullhead and largemouth bass; variations may be related to different life-history strategies for each fish species.
- Site-to-site differences in biomarkers suggest that natural reproduction in certain fish populations may be at risk due to changes in the function of their endocrine systems at selected locations in the basin.
- The above findings need to be confirmed and additional concerns need to be addressed by further investigation of:
 - the normal timing of reproductive maturity and magnitude of seasonal biomarker fluctuations in targeted fish species,
 - loads of toxic metals, PCBs, other organic contaminants, pharmaceuticals, and personal-care products that occur in surface water and sediments at various locations across the basin,
 - the effects that altered endocrine biomarker levels may have on the reproductive success of selected fish species,
 - the effects that altered endocrine biomarker levels may have on the viability and quality of local fish populations, and
 - the effects that other factors, such as habitat characteristics, suitability, and interrelations with colocated fish populations might have on targeted fish populations at selected locations throughout the Hudson River Basin.

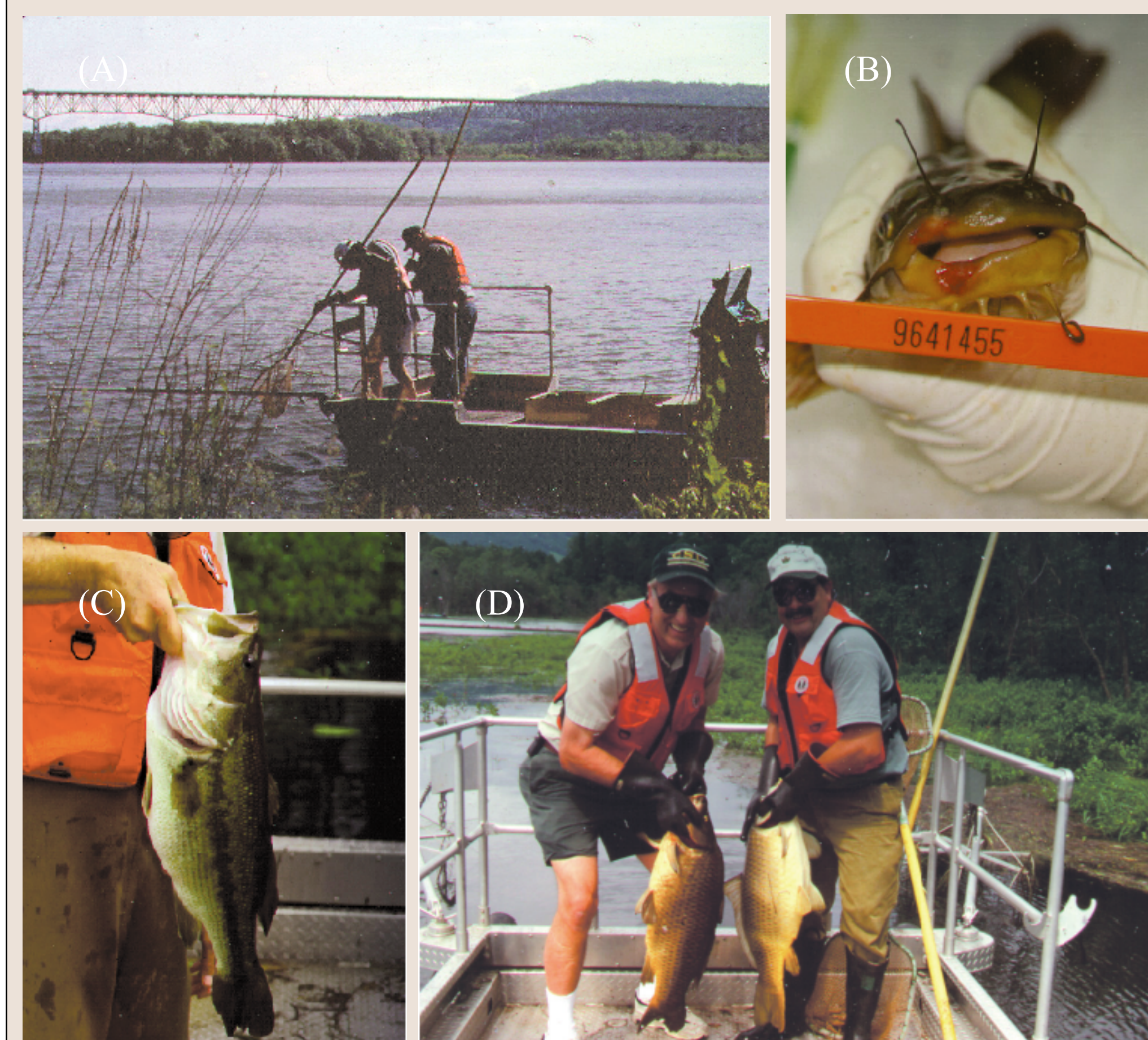


Figure 14. (A) electroshocking at Catskill, (B) brown bullhead with lesions and burnt barbules, (C) largemouth bass, and (D) common carp.

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